(12) UK Patent Application (19) GB (11) 2 344 493 (13) A

(43) Date of A Publication 07.06.2000

(21) Application No 9819855.9

(22) Date of Filing 12.09.1998

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(51) INT CL$^7$
H04L 27/233 7/04

(52) UK CL (Edition R)
H4P PAL PSB

(56) Documents Cited
GB 2232852 A GB 2170978 A US 5625573 A
US 4527278 A

(58) Field of Search
UK CL (Edition Q) H4P PAL PSB
INT CL$^6$ H04L 7/04 27/22 27/227 27/233 27/38
Online : EPODOC

(54) Abstract Title

# Automatic frequency correction

(57) The method for automatic frequency correction is for use in an existing Digital Enhanced Cordless Telecommunications (DECT) system. The method comprises the steps of measuring a phase difference between an output of two correlators which operate on a received signal and employ segments of a known transmitted waveform separated by a known time difference as reference signals, calculating a frequency offset estimate (54) based on said measured phase difference, correcting said received signal (56) by an amount corresponding to said calculated frequency offset estimate, and repeating said measuring, calculating and correcting steps in a plurality of stages (58-64) in order to achieve a predetermined accuracy of said carrier frequency offset estimate. The method will be used in a DECT system in a Wireless Local Loop application which can tolerate multi-path conditions to provide a reliable telecommunication system for use with both POTS and ISDN services. The system will be easy to install and not require a licence, thus making it less expensive than current cordless telecommunication systems.

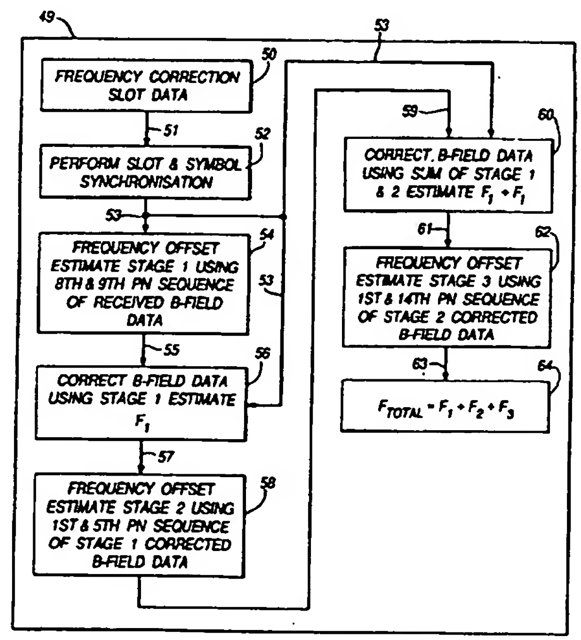


Fig.2

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

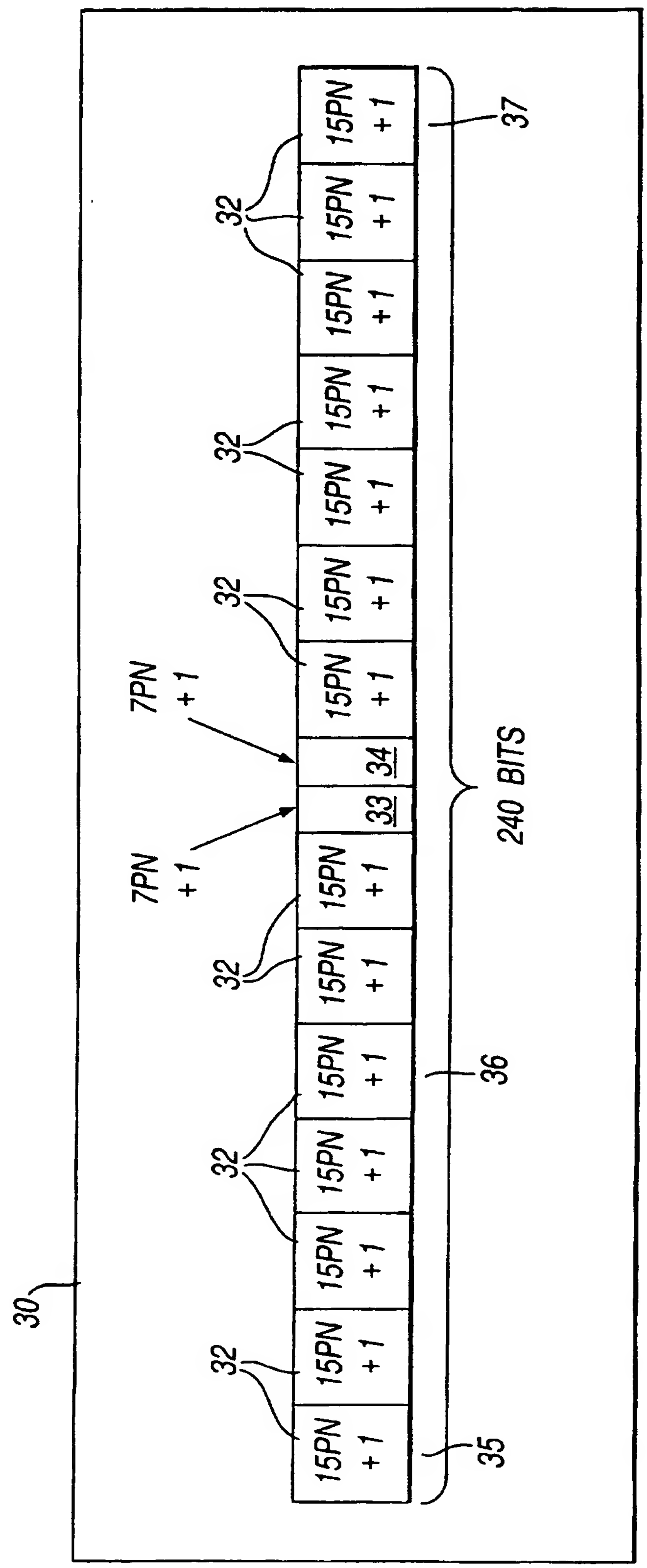


Fig.1

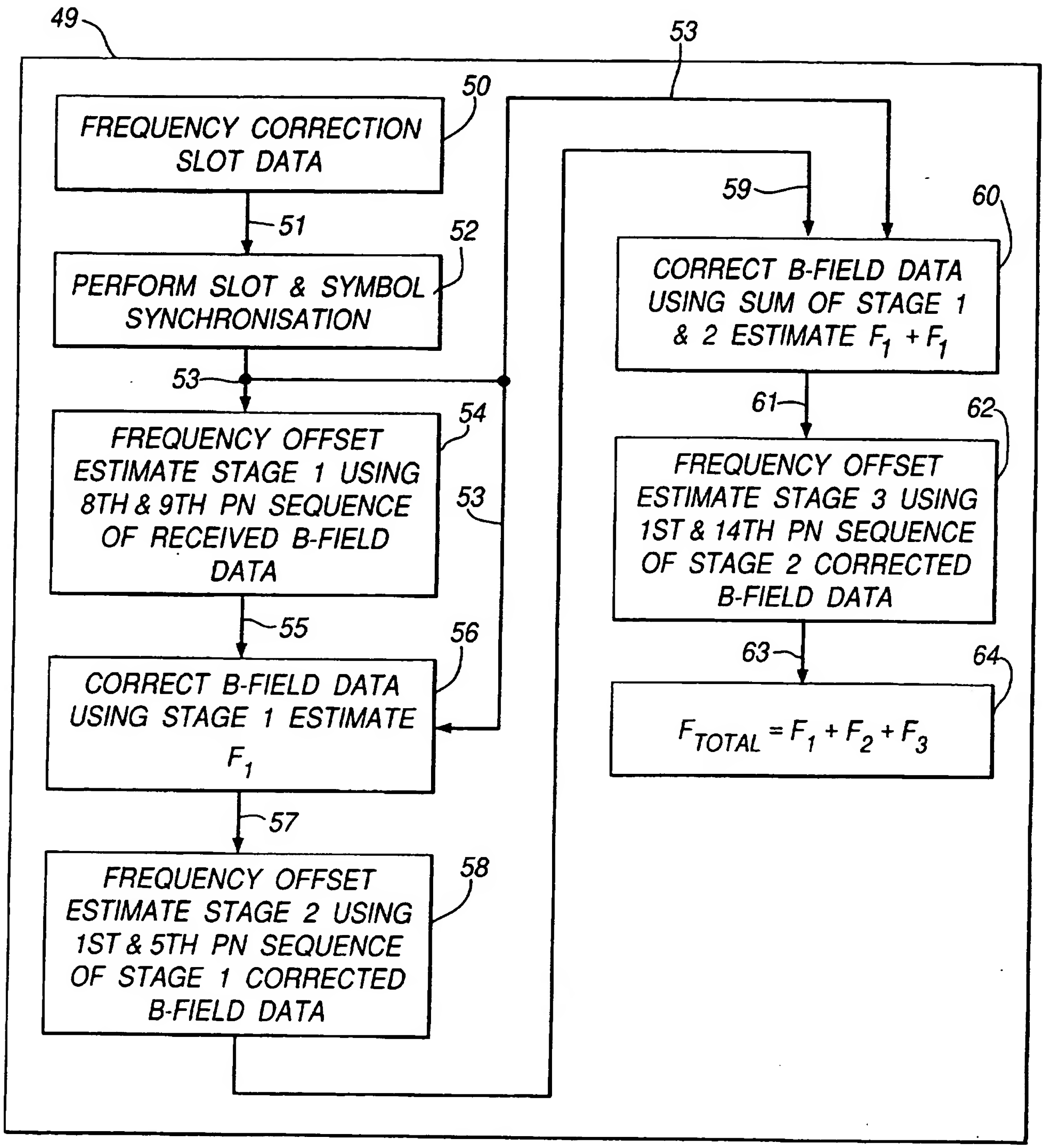
49
53
50
FREQUENCY CORRECTION SLOT DATA
51
52
PERFORM SLOT & SYMBOL SYNCHRONISATION
53
54
FREQUENCY OFFSET ESTIMATE STAGE 1 USING 8TH & 9TH PN SEQUENCE OF RECEIVED B-FIELD DATA
53
55
56
CORRECT B-FIELD DATA USING STAGE 1 ESTIMATE $F_1$
57
58
FREQUENCY OFFSET ESTIMATE STAGE 2 USING 1ST & 5TH PN SEQUENCE OF STAGE 1 CORRECTED B-FIELD DATA
59
60
CORRECT B-FIELD DATA USING SUM OF STAGE 1 & 2 ESTIMATE $F_1 + F_1$
61
62
FREQUENCY OFFSET ESTIMATE STAGE 3 USING 1ST & 14TH PN SEQUENCE OF STAGE 2 CORRECTED B-FIELD DATA
63
64
$F_{TOTAL} = F_1 + F_2 + F_3$

Fig.2

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# METHOD FOR AUTOMATIC FREQUENCY CORRECTION

The present invention relates to the field of automatic frequency correction. More specifically, the present invention relates to a method for automatic frequency correction for use in an existing Digital Enhanced Cordless Telecommunications (DECT) system.

There is a growing need for reliable radio frequency (RF) telecommunications networks which are affordable and easy to install. DECT systems are traditionally less expensive that other known types of RF telecommunication systems, such as GSM based systems, due to the absence of licence requirements.

The present invention relates to the use of a DECT system in a Wireless Local Loop application which can tolerate multi-path conditions to provide a reliable telecommunication system for use with both POTS and ISDN services. The system will be easy to install and not require a licence, thus making it less expensive than current cordless telecommunication systems.

Wireless Local Loop systems consist of several Radio Base Stations (RBS) and Radio Network Terminations (RNT). An RF transmitter is located in each RBS and is used to transmit both speech and data signals. The RF part also comprises of a coherent modulator in the transmit section and a linear receiver with IQ conversion to baseband. Associated with the RF part is a baseband part with significant digital signal processing (DSP) capabilities. One of the required functions of the baseband part is to perform an automatic frequency correction (AFC) using existing DECT MAC layer protocols and physical layer structure.

DECT MAC layer protocols are well known in the art of radio telecommunications as disclosed in prior art documents ETS 300 175-2, September 1996, 2nd Edition Radio Equipment and Systems; (Digital Enhanced Cordless Telecommunications), Common Interface Port 2: Physical Layer and ETS 300 175-3, September 1996, 2nd Edition Radio Equipment and Systems; (Digital Enhanced Cordless Telecommunications), Common Interface Port 3: Medium Access Control Layer.

A technical problem exists in that conventional DECT receiver architecture is non-coherent, comprising of a simple Limiter-Discriminator structure. To provide the bit error rate (BER) performance to support ISDN services within a Wireless Local Loop environment, a coherent architecture is preferred. However, the phase of the signal now needs to be tracked, and thus some form of automatic frequency correction is required.

A technical problem of providing an automatic frequency correction method for use in existing DECT systems is addressed by the automatic frequency correction method according to the present invention.

According to the present invention there is provided a method for automatic frequency correction for use within a radio communication system wherein said method comprises the steps of:

measuring a phase difference between an output of two correlators which operate on a received signal and employ segments of a known transmitted waveform separated by a known time difference as reference signals,

calculating a frequency offset estimate based on said measured phase difference, correcting said received signal by an amount corresponding to said calculated frequency offset estimate,

repeating said measuring, calculating and correcting steps in a plurality of stages in order to achieve a predetermined accuracy of said carrier frequency offset estimate.

Said step of measuring a phase difference may employ segments of a basic DECT slot structure as said reference signals. Said reference signals may occupy 240 bits of a B-field and consist of a sequence of pseudo noise sequences.

A first stage of said plurality of stages may employ a transmitted signal corresponding to a length seven pseudo-noise sequence of said B-field data as identical reference signals of said two correlators, calculates a first frequency offset estimate, and corrects said received signal by said first frequency offset estimate.

A second stage of said plurality of stages may employ a transmitted signal corresponding to a first and a fifth length 15 pseudo noise sequence of said B-field data as identical reference signals of said two correlators, calculates a second frequency offset estimate, and corrects said received signal by the sum of the said first frequency offset estimate and said second frequency offset estimate.

A third stage of said plurality of stages may employ a transmitted signal corresponding to a first and a fourteenth length 15 pseudo noise sequence of said B-field data as identical reference signals of said two correlators, calculates a third frequency offset estimate, and corrects said received signal by sum of said first, said second and said third frequency offset estimates.

Furthermore, according to the present invention, said automatic frequency correction method may be used in a DECT system. Said DECT system may be used in a Wireless Local Loop application.

The present invention offers several technical advantages. By performing the carrier frequency offset estimation in the RNT only, both the signal received by the RNT and transmitted by the RNT may be corrected by the carrier frequency offset estimates, and thus the network overhead is reduced. In addition, the method according to the present invention reduces the processing requirements of the base station.

While the principle advantages in the features of the invention have been described above a greater understanding and appreciation of the invention may be obtained by referring to the following drawings and detailed description of a preferred embodiment, presented by way of example only, in which;

Figure 1 shows the Frequency Correction B-Field Data,

Figure 2 shows a block diagram of the main stages of the Automatic Frequency Correction method.

According to the present invention, the carrier frequency offset estimation and correction function is performed in the RNT only. The estimation process derives the frequency offset between the RBS and RNT reference oscillators.

Prior to decoding the received signal the RNT must correct the frequency offset present in the received signal to prevent a long burst of errors at the output of the phase coherent detector. This functionality is not required in the RBS as long as the RNTs offset their transmitting frequencies appropriately. This provides the technical advantage of reducing the processing requirements of the basestation.

The maximum carrier frequency offset between an RBS and RNT is known in the art to be typically ±32kHz. However, the frequency estimation algorithm must be accurate to within ±100Hz. This has been determined via simulation as the maximum frequency offset that can be tolerated by the Maximum Likelihood Sequence Estimation (MLSE) detector before a serious degradation in performance occurs.

The frequency estimation algorithm according to the present invention is based on measuring the phase difference between the output of two correlators which use segments of a known transmitted waveform that are separated by a known time difference as reference signals. The carrier frequency offset estimate is calculated from this phase difference estimate.

In figure 1 a portion of the B field of the basic DECT slot structure, which is well known in the art, is shown. The frequency estimation process requires a known signal to be transmitted in the B field of special frequency estimation slots. The reference signal occupies 240 bits of the B field 30 and consists of sequences of pseudo noise (PN) sequences 32. All PN sequences 32 are padded with a single bit. This frequency correction slot is physically distinct from the other slots used within the DECT system. This is due to the fact that without frequency correction information no transmitted data can be detected reliably and thus no frame synchronisation information can be obtained by the RNT. After power up the RNT must search for frequency correction slots by detecting the physical size of the slot, attain slot and symbol synchronisation and perform the frequency estimation process in order to attain frequency synchronisation with the system. Once this has been achieved then the A field, which is well known in the art, may be

detected, frequency corrected, and decoded to provide any necessary system information of use to the DECT System.

The frequency estimation process according to the present invention occurs in three stages. This is due to two incompatible requirements of the measuring process. The first requirement is that, in order to generate accurate phase difference estimates, the two reference sequences must be separated in time such that the phase rotations caused by a ±100Hz offset must be large enough such that the phase estimate is not significantly affected by noise on the received signal. Secondly, in order for a wide range of offsets to be measured, the time separation of the reference signals must be short enough to ensure that the phase difference is within the range $[+\pi, -\pi]$ given the maximum allowed carrier offset.

These two requirements cannot be met in a single stage estimation process based on measuring phase differences. Thus a multiple stage estimation process is used with frequency correction of the reference signal occurring between each stage of the process.

Figure 2 shows the automatic frequency correction (AFC) process 49 in block diagram form. In figure 2, frequency correction slot data 50 is input to the AFC process 49. Slot and symbol synchronisation 52 is performed on the received data 51. The first stage 54 of the AFC process uses the transmitted signal corresponding to the length seven PN sequence as identical reference signals for the two correlators. The two correlators correlate the reference signal with the $8^{th}$ and $9^{th}$ PN sequence, 33 and 34 respectively, of the received data 51. As symbol synchronisation 52 will have already occurred, the position of these sequences, 33 and 34, in the signal stream 53 received at the first stage

54 is already determined and thus eliminates the need to search for a peak in the correlator output. Thus the correlation must be performed at two points only. The difference in phase of the correlator outputs is calculated and divided by the time difference between the two sequences (6.94μs) to give the first stage radian frequency offset $F_1$ 55. $F_1$ is then input to 56 where the received B-field data 53 is corrected by $F_1$. The correction is performed by multiplying the signal by the complex exponential, exp $(-j.2\pi.F_1t)$. The maximum frequency offset allowable is given by $\Delta\phi|_{MAX}/(2\pi.8T_S)=\pm72kHz(\Delta\phi|_{MAX}=\pm\pi)$, where $T_S$ is the symbol period. Phase ambiguities resulting from noise in the phase estimation process are highly unlikely to be greater then $\pi$ radians even when the offset is ±36kHz. Simulations show that the error in this first stage estimate 54 to be <<5kHz when operating in a two path Rayleigh fading channel with a Signal-to-noise ratio = 20dB.

The output 57 of 56, which is the B-field data corrected by $F_1$, is input to the second stage of the AFC process 58. The second stage of estimation uses the first 35 and the fifth 36 length fifteen PN sequences as the correlator reference signals. The second stage frequency offset $F_2$ 59 is calculated in the same manner as was the first stage offset $F_1$. $F_2$ is then input to 60 where the received B-field data 53 is corrected by the sum of $F_1$ and $F_2$. The maximum frequency offset that the second stage of estimation can correct is $\pm1/(128T_S)=\pm9kHz$ which is sufficiently greater than the likely error range of the first stage estimation process.

The output 61 of 60, which is the B-field data corrected by the sum of $F_1$ and $F_2$, is input to the third stage of the AFC process 62. The third stage of estimation uses the first 35 and fourteenth 37 length fifteen PN sequences as the correlator reference signals. The third stage frequency

offset $F_3$ 63 is calculated in the same manner as was $F_1$ and $F_2$. The maximum frequency offset that the third stage of estimation can correct is $\pm 1(448T_S) \approx \pm 2.6$kHz which is significantly greater than the likely combined error of the first and second stage estimation processes.

The total frequency offset estimate $F_{TOTAL}$ 64 is given by the sum of the estimates of all three stages ($F_{TOTAL}=F_1 + F_2 + F_3$). The received data 51 is then corrected by $F_{TOTAL}$ 64. In one embodiment of the present invention, the total frequency offset estimate 64 may be averaged with previous estimates to remove sporadic variations. Such variations may occur due to a combination of a large frequency offset and noise causing phase ambiguities in the phase estimation process. The length of the averaging can depend on how often the frequency correction packets are transmitted and also on drift in the RBS and RNT reference oscillators. As is well known in the art, reference oscillators may drift due to, amongst other things, temperature variations.

The present invention substantially corrects for variations in the frequency offsets. Sources of frequency offset variations include temperature changes and oscillator manufacturing tolerances. As will be appreciated by those skilled in the art, other sources of frequency offset variations exist, such as Doppler shifts, and are included in the scope of the present invention.

In alternative embodiment, no averaging takes place and each offset estimate overrides all previous estimates. The most recent estimate is then used to correct all subsequent slots. This embodiment provides a worst case scenario in which isolated and significantly erroneous estimates are made. These errors can arise sporadically under

certain combination of a large frequency offset and noise causing phase ambiguities in the phase difference estimation process.

In yet another embodiment of the present invention, more sophisticated measures, other than averaging, might be employed to prevent outlying estimates corrupting the frequency estimate.

The frequency estimation function 49 should occur whenever a frequency correction slot is transmitted by an RBS and when instructed to do so by the RNT control system. In order to do this, the RNT control system must have a knowledge of when to expect the slot and on which carrier frequency. This information could be stored in the A field of previous slots received by the RNT control system. The rate at which the frequency correction slots are transmitted from the RBSs will depend on allowable network overheads and the expected time drift of the reference oscillators in the RBS and RNTs.

As will be appreciated by those skilled in the art, various modifications may be made to the embodiment hereinbefore described without departing from the scope of the present invention. Specifically, the automatic frequency estimation and correction process according to the present invention may be applied to systems other than DECT systems, such as Personnel Wireless Telephone (PWT) based systems.

## CLAIMS

1. A method of automatic frequency correction for use within a radio communication system wherein said method comprises the steps of:

measuring a phase difference between an output of two correlators which operate on a received signal and employ segments of a known transmitted waveform separated by a known time difference as reference signals,

calculating a frequency offset estimate based on said measured phase difference,

correcting said received signal by an amount corresponding to said calculated frequency offset estimate,

repeating said measuring, calculating and correcting steps in a plurality of stages in order to achieve a predetermined accuracy of said carrier frequency offset estimate.

2. An automatic frequency correction method as claimed in Claim 1 wherein said step of measuring a phase difference employs segments of a basic DECT slot structure as said reference signals.

3. An automatic frequency correction method as claimed in Claim 2 wherein said reference signals occupy a predetermined number of bits of a B-field and consist of a sequence of pseudo noise sequences.

4. An automatic frequency correction method as claimed in Claim 3 wherein said predetermined number of bits is 240.

5. An automatic frequency correction method as claimed in Claims 3 or 4 wherein a first stage of said plurality of stages employs a transmitted signal corresponding to a length seven pseudo-noise sequence of said B-field data as identical reference signals of said two correlators, calculates

a first frequency offset estimate, and corrects said received signal by said first frequency offset estimate.

6. An automatic frequency correction method as claimed in Claim 5, wherein said second stage of said plurality of stages employs a transmitted signal corresponding to a first and fifth length 15 pseudo noise sequence of said B-field data as identical reference signals of said two correlators, calculates a second frequency offset estimate, and corrects said received signal by the sum of said first and said second frequency offset estimates

7. An automatic frequency correcting method as claimed in Claim 6, wherein said third stage of said plurality of stages employs a transmitted signal corresponding to a first and a fourteenth length 15 pseudo noise sequence of said B-field data as identical reference signals of said two correlators, calculates a third frequency offset estimate, and corrects said received signal by the sum of said first, said second and said third frequency offset estimate.

8. An automatic frequency correction method as claimed in Claim 7, wherein a total frequency offset correction estimation, which is the sum of said first, second, and third stages, yields said carrier frequency offset estimate with an accuracy of +/- 100 Hertz.

9. An automatic frequency correction method as claimed in Claim 8, wherein said total frequency offset estimate is averaged with previous total frequency offset estimates.

10. An automatic frequency correction method as claimed in Claims 8 or 9, wherein each total frequency offset estimate overrides all previous total frequency offset estimates.

11. An automatic frequency correction method as claimed in any preceding claim, wherein said automatic frequency correction method substantially corrects for variations in the frequency offset.

12. An automatic frequency correction method as claimed in any preceding claim wherein the said automatic frequency correction method is used in a DECT system.

13. An automatic frequency correction method as claimed in Claim 12, wherein the said DECT system is used in a Wireless Local Loop application.

14. An automatic frequency correction method as claimed in any preceding claim wherein the said automatic frequency correction method occurs in a baseband part of a radio communication system.

15. An automatic frequency correction method as claimed in any preceding claim wherein said automatic frequency correction method is triggered by a radio base station.

16. An automatic frequency correction method as claimed in any preceding claim wherein said automatic frequency correction method is triggered by a radio network termination.

17. An automatic frequency correction method as claimed in any of Claims 2 to 16, wherein said method uses a DECT slot that is physically distinct from other DECT slots, thereby allowing said radio network termination to detect a frequency correction slot.

18. An automatic frequency correction method as claimed in any of Claims 1 to 11 wherein said automatic frequency correction method is used in a PWT system.

19. An automatic frequency correction method as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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**Application No:** GB 9819855.9
**Claims searched:** 1-19

**Examiner:** Keith Williams
**Date of search:** 7 April 1999

## Patents Act 1977
## Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:
UK Cl (Ed.Q): H4P (PAL, PSB)
Int Cl (Ed.6): H04L 7/04, 27/22, 27/227, 27/233, 27/38
Other: Online EPODOC

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| A | GB 2232852 A | Technophone - see abstract (& EP 0400782, US 5081652) | 1 |
| A | GB 2170978 A | Harris Corp. - see abstract (& WO 85/04999, US 4599732) | 1 |
| A | US 5625573 | Hughes Electronics - see abstract; | 1 |
| X | US 4527278 | U.S.Philips Corp. - see abstract; column 10,lines 23 onwards | 1 |

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